Geological Survey
of Canada

CURRENT RESEARCH
2002-E17

Recurrence interval of seismically triggered mass-transport deposition at Orphan Knoll, continental margin off Newfoundland and Labrador

Michael W. Toews and David J.W. Piper

2002

Natural Resources Canada
Ressources naturelles Canada

Canada

©Her Majesty the Queen in Right of Canada 2002
ISSN 1701-4387
Catalogue No. M44-2002/E17E
ISBN 0-660-18859-7

Available in Canada from the
Geological Survey of Canada Bookstore website at:
http://www.nrcan.gc.ca/gsc/bookstore (Toll-free: 1-888-252-4301)

A copy of this publication is also available for reference by depository libraries across Canada through access to the Depository Services Program's website at http://dsp-psd.pwgsc.gc.ca

Price subject to change without notice

All requests for permission to reproduce this work, in whole or in part, for purposes of commercial use, resale, or redistribution shall be addressed to: Earth Sciences Sector Information Division, Room 402, 601 Booth Street, Ottawa, Ontario K1A 0E8.

Authors' address

M.W. Toews (toews@gsca.nrcan.gc.ca)
D.J.W. Piper (dpiper@nrcan.gc.ca)
Geological Survey of Canada
GSC Atlantic
1 Challenger Drive
P.O. Box 1006
Dartmouth, Nova Scotia
B2Y 4A2

Publication approved by GSC Atlantic

Recurrence interval of seismically triggered mass-transport deposition at Orphan Knoll, continental margin off Newfoundland and Labrador[1]

Michael W. Toews and David J.W. Piper

Toews, M.W. and Piper, D.J.W., 2002: Recurrence interval of seismically triggered mass-transport deposits at Orphan Knoll, continental margin off Newfoundland and Labrador; Geological Survey of Canada, Current Research 2002-E17, 8 p.

Abstract: High-resolution Huntec sparker seismic profiles from 3400 m water depth on the southeastern flank of Orphan Knoll have been correlated to long cores that extend back to the last interglacial (marine isotope stage 5). Distinctive interglacial and glacial acoustic facies interbed with local geographically restricted acoustic facies characteristic of mass-transport deposits. The mass-transport deposits appear to be earthquake triggered, with a recurrence interval of about 70 000 years.

Résumé : Au moyen d'un étinceleur Huntec à haute résolution, on a tracé des profils sismiques du versant sud-est du dôme Orphan, à une profondeur d'eau de 3 400 m. Une corrélation a été établie entre ces profils et de longues carottes renfermant des matériaux datant d'aussi loin que le dernier interglaciaire (stade isotopique marin 5). Sont interstratifiés localement des faciès acoustiques interglaciaires et glaciaires distinctifs et des faciès acoustiques limités géographiquement et caractéristiques de dépôts de mouvement de masse. Ces derniers semblent avoir été déplacés lors de séismes selon un intervalle de récurrence d'environ 70 000 ans.

[1] Contribution to PERD project 532211.

INTRODUCTION

Purpose of this study

Estimating the recurrence interval of earthquakes around the Grand Banks of Newfoundland is important for quantitative risk analysis for offshore development. Past earthquakes may be indicated by the presence of subsurface horizons characterized by sediment failure over a large area that downslope may lead to mass-transport deposits (rotational slumps, debris-avalanche deposits, or debris-flow deposits). On the continental slope, mass-transport deposits may have been triggered by processes other than earthquakes, such as by glacial advance. Mass-transport deposits located on the flanks of isolated highs, such as Orphan Knoll (Fig. 1), however, are likely triggered by earthquakes, as sedimentation rates are low and there are few other likely triggering mechanisms. We have examined late Quaternary stratigraphy on southern Orphan Knoll using high-resolution seismic reflection profiles in order to identify mass-transport deposits, and have developed a chronology based on previously published isotope stratigraphy from piston cores.

Geological setting and available data

Orphan Knoll (Fig. 1) is located 600 km east of Newfoundland and Labrador and 150 km west of the Northwest Atlantic Mid-Ocean Channel (NAMOC). It is a fragment of continental crust that detached from North America during continental rifting (Keen and Beaumont, 1990) and is formed by fault-bounded blocks that deepen southward from a crest in 1800 m water depth. Its lower flanks are partly mantled by late Cenozoic drift deposits.

Multibeam bathymetric data were collected from southern Orphan Knoll by the *USCGS Healy* and kindly provided to the GSC Atlantic. A bathymetric map derived from these data (Fig. 2) shows a ridge south of the main part of Orphan Knoll bounded on the east by a fault-line scarp. Piston cores HU91-045-094 (Hillaire-Marcel et al., 1994) and MD99-2237 (Hillaire-Marcel and Turon, 1999) were collected 6 km northeast of this fault-line scarp. These cores contain principally hemipelagic and ice-rafted sediments and provide a chronology at least back to marine isotope stage 5a at about 85 ka. Regional bathymetry also indicates that the core sites are at least 500 m above the turbidite basin plain, suggesting that although distal turbidite muds could be deposited in the study area, turbidite sands and mass-transport deposits are not likely from the NAMOC system.

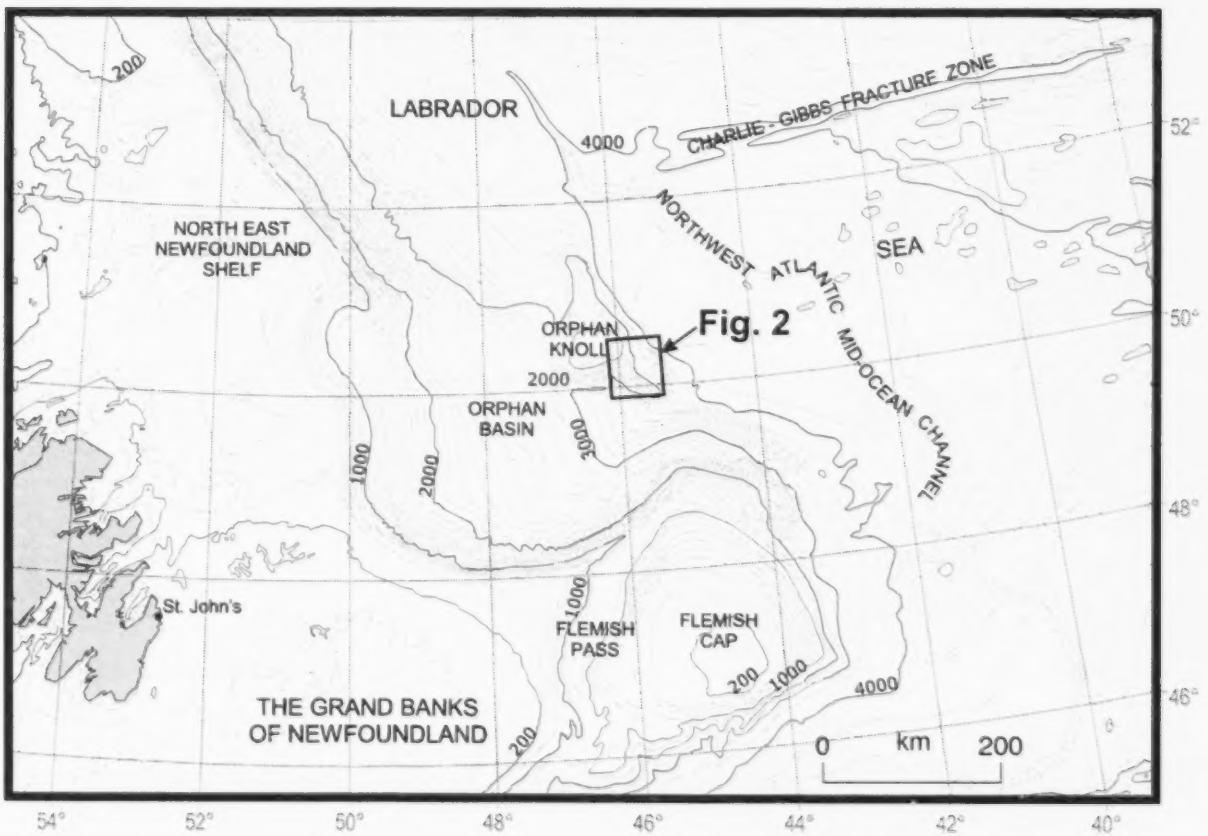

Figure 1. Regional map showing the location of Orphan Knoll.

At the Deep Sea Drilling Program (DSDP) Site 111 on the crest of Orphan Knoll (Fig. 2), 127 m of Pleistocene ice-rafted and hemipelagic sediment were penetrated, corresponding to an average sedimentation rate of 0.062 m/ka (Shipboard Scientific Party, 1972). This indicates high sedimentation rates from ice-rafted and glacial-plume deposits. The average sedimentation rate in core HU91-045-94 on the flank of Orphan Knoll over the past 75 ka is estimated to be 0.117 m/ka (Hillaire-Marcel et al., 1994).

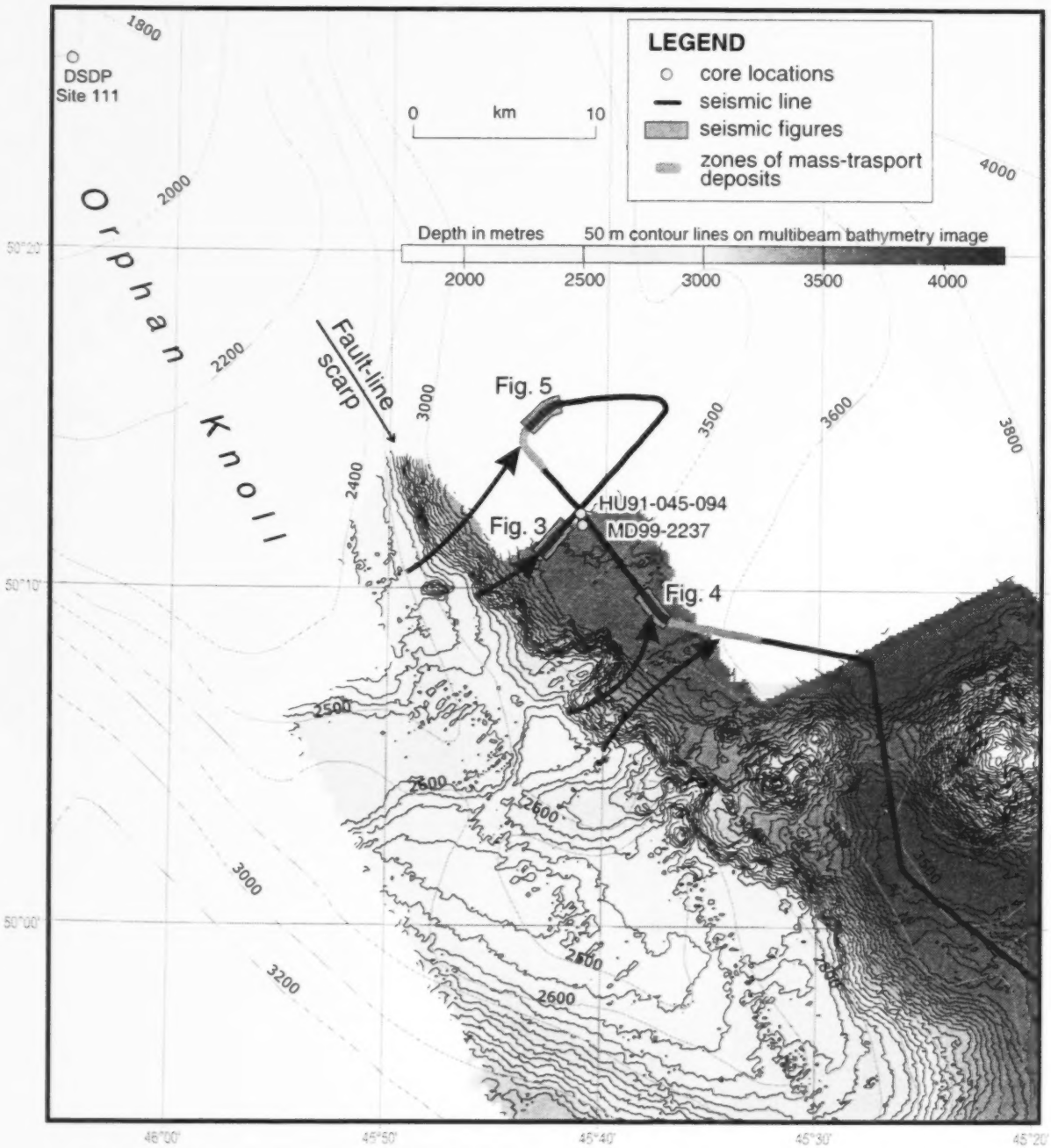

Figure 2. *Detailed bathymetric map of the southeastern part of Orphan Knoll, showing location of cores and seismic reflection profiles. Zones of mass-transport deposits and their possible source on the fault-line scarp are indicated.*

SEISMIC REFLECTION PROFILES

High-resolution Huntec sparker seismic-reflection data were obtained from the *CCGS Hudson* during cruise 2001-043 across the core sites and near the base of the fault-line scarp. The system was towed about 100 m below sea surface. Signals were filtered at 500 to 5000 Hz with spreading loss gain recovery. The signals were displayed in analogue hard copy on an EPC9800 thermal chart recorder with a 500 ms sweep rate. Firing rate was 0.5 s (1 m spacing). Analysis of the received signal shows a frequency bandwidth of 500 to 2500 Hz with a centre frequency of about 1500 Hz. This spectrum translates to a maximum vertical resolution of about 0.20 m.

A seismic stratigraphy was developed for the study area and defined near the only crossover in the data set, which is near the locations where the piston cores were obtained (Fig. 2). The following regional reflections were defined (Fig. 3): purple, at 12 ms subbottom, at the base of a packet of high-amplitude reflections; blue, at 19 ms subbottom, a high-amplitude reflector in the middle of a packet of low-amplitude reflections; pink, at 28 ms subbottom, at the top of a packet of high-amplitude reflections; orange, at 48 ms subbottom, the lower of two parallel, high-amplitude, continuous reflections; green, at 70 ms subbottom, and red, at 80 ms subbottom, are deeper, high-amplitude reflections that can be traced regionally.

Four seismic facies are recognized. Facies A, with parallel, closely spaced, high-amplitude reflections, is well developed above the purple reflection and below the pink and orange reflections (Fig. 3, 4). Facies B, with subparallel, low-amplitude reflections with a few medium-amplitude reflections, is well developed between the purple and orange reflections and may be present between the green and red reflections. Facies C, an acoustically incoherent facies that pinches out laterally (Fig. 3, 4, 5) or abruptly abuts stratified facies, has an upper surface that commonly appears rough and the general acoustic character of mass-transport deposits. Facies D has moderate-amplitude, discontinuous, and variably dipping reflections, for example at the base of slope near pink in Figure 3 and from seafloor to blue in Figure 5. Part of this irregularity appears to result from deposition over the irregular top of a mass-transport deposit, but part of it may result from irregular deposition from powerful bottom currents, particularly in the moat at the base of the fault-line scarp (Fig. 3).

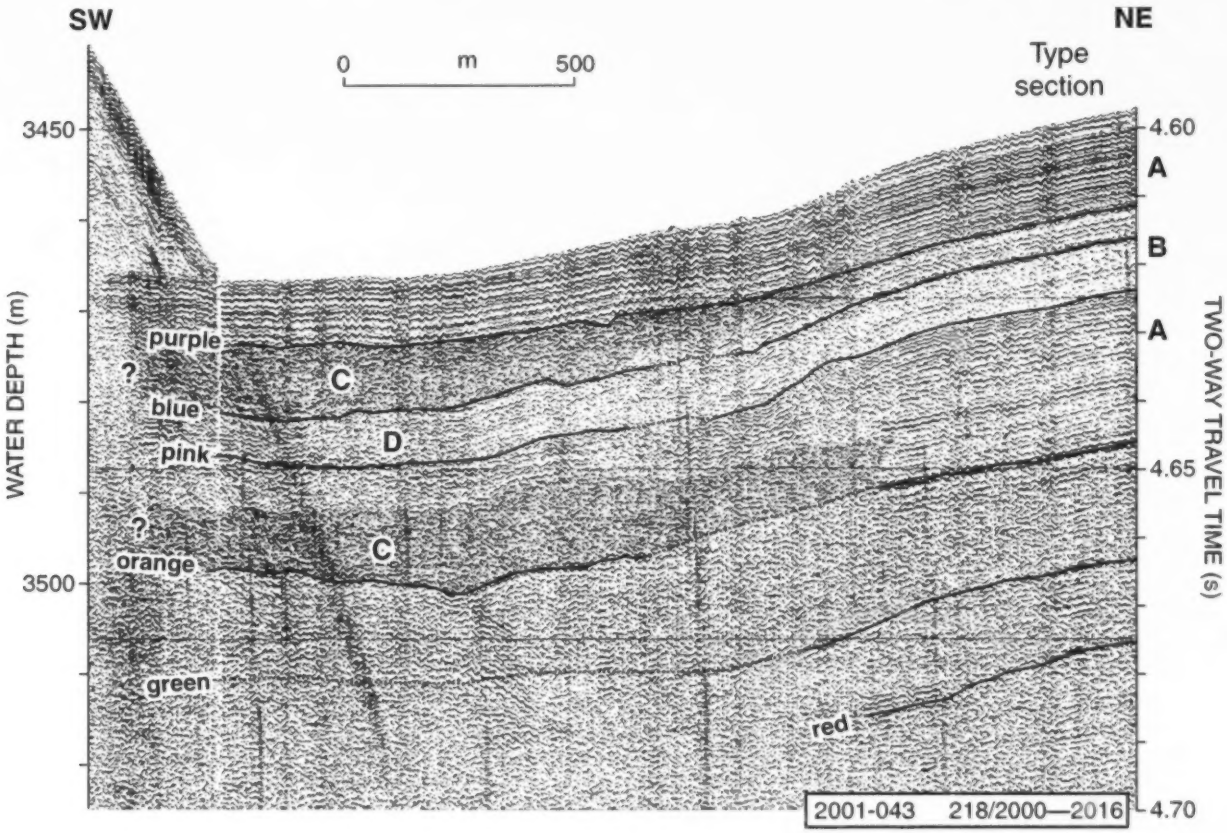

Figure 3. *Huntec sparker profile showing type section for the seismic stratigraphy and the moat at the base of the fault-line scarp. Examples of acoustic facies A through D are also shown.*

103-04446/

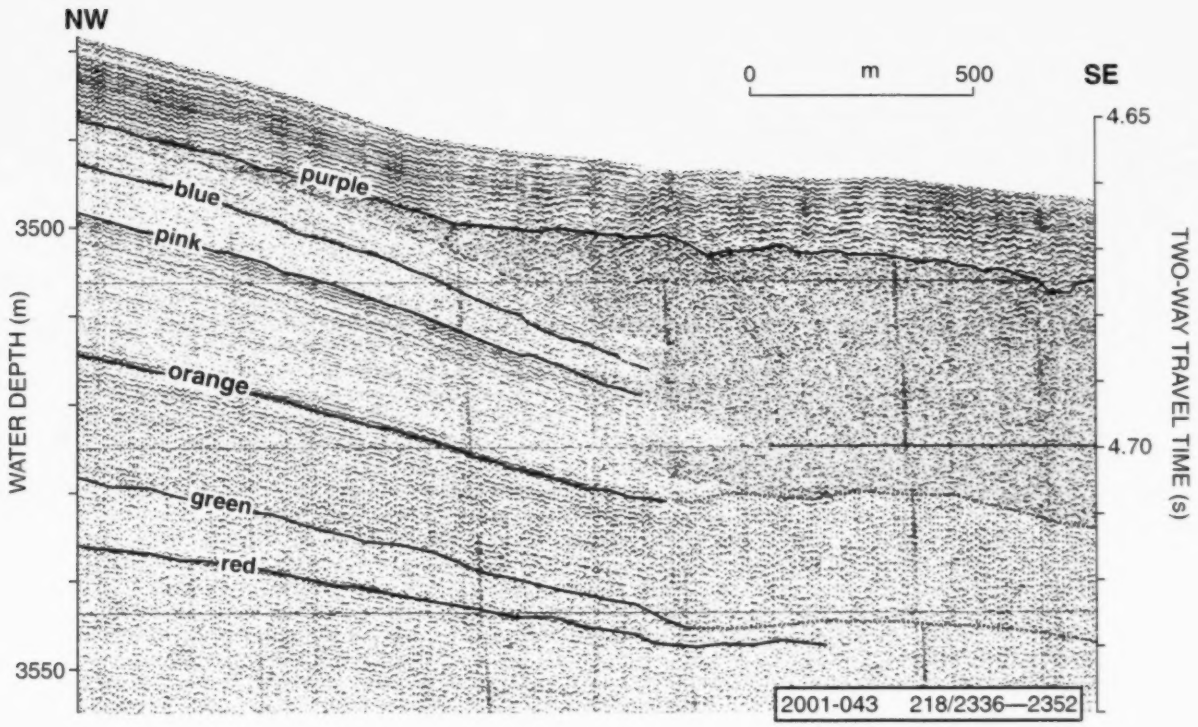

Figure 4. *Huntec sparker profile south of the core sites showing amalgamated mass-transport deposits.*

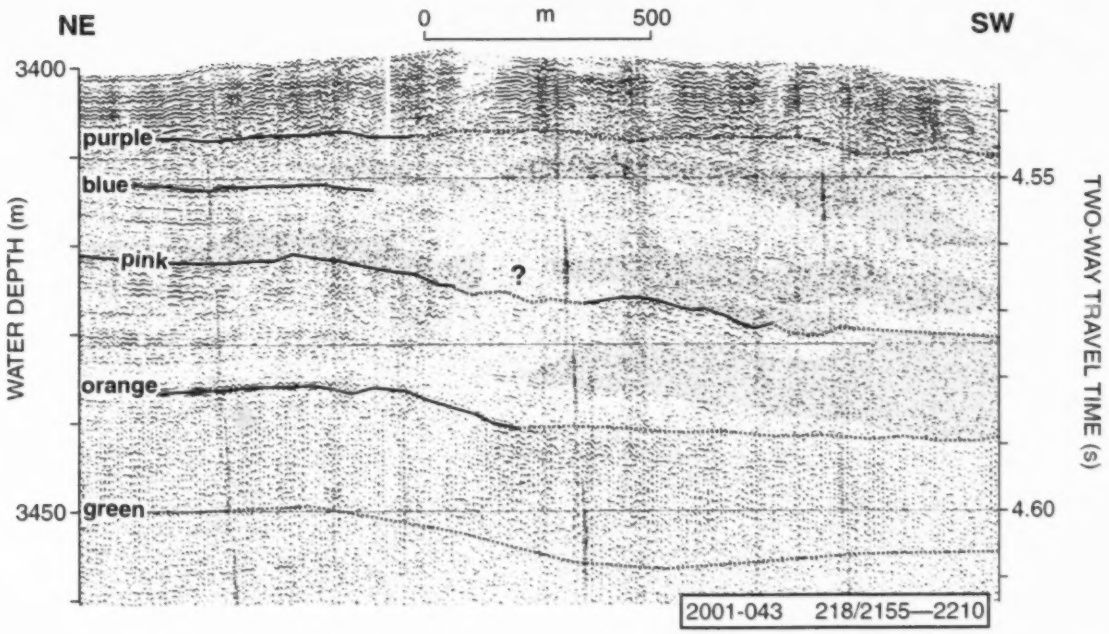

Figure 5. *Huntec sparker profile north of the core sites showing the occurrence of mass-transport deposits.*

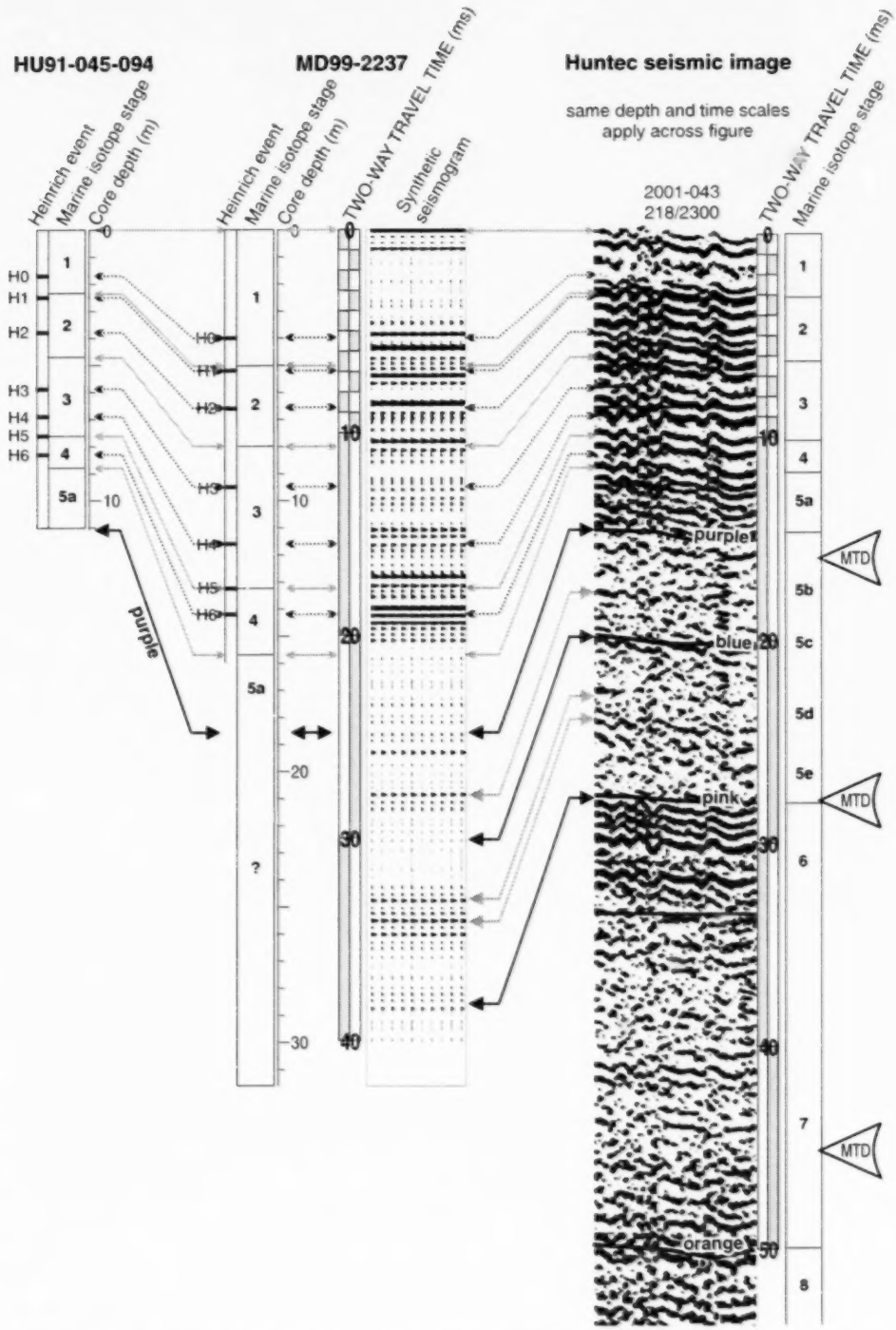

Figure 6. *Comparison of core HU91-045-094, core MD99-2237 (stretched), a synthetic seismogram based on core MD99-2237, and the sparker seismic record. Correlation between the two cores is from Hillaire-Marcel and Turon (1999) and is based on magnetic susceptibility profiles. The same correlation lines are used to link the synthetic seismogram from the stretched core to the Huntec seismic profile, which is displayed on the same depth scale as the cores (and can therefore be directly correlated with core HU91-045-094, which is not stretched). The stratigraphic position of the three major mass-transport deposits (MTD) is also shown.*

The mass-transport facies found in the seismic data have been identified in three geographic zones, shown on the map in Figure 2 and illustrated in Figures 3, 4, and 5. The bases of mass-transport deposits appear to be erosional, as noted in other studies (e.g. Piper et al., 1997; Posamentier, 2001). They pinch out laterally at a single stratigraphic horizon. Mass-transport deposits can be placed within the seismic stratigraphy and occur at the same stratigraphic horizon in different geographic zones. The shallowest mass-transport deposit pinches out laterally just below the purple reflection (Fig. 3, 4), although where the deposit forms positive relief, the first continuous overlying reflection appears to be purple. A second, less widespread, deposit occurs a short distance above pink, with the precise stratigraphic level of lateral pinchout being unclear (Fig. 5). A third mass-transport deposit overlies the orange reflector (Fig. 3, 5) and pinches out about 5 ms above orange.

CORRELATION WITH CORES

A core (MD99-2237) 32 m long collected from the *Marion Dufresne* using a Calypso coring system (Hillaire Marcel and Turon, 1999) has continuous downcore measurements of magnetic susceptibility, bulk density, and P-wave velocity. Piston core HU91-045-094 (Hillaire Marcel et al., 1994) has downcore magnetic susceptibility measurements and an oxygen isotope stratigraphy confirmed by radiocarbon dating, Heinrich layers, and ash layers. The Calypso coring system historically has been known to induce 'stretching' of about 30% (e.g. Piper et al., 1999; Hiscott et al., 2000), particularly in the upper part of cores. Hillaire Marcel and Turon (1999) used the magnetic susceptibility records to correlate core MD99-2237 with core HU91-045-094, which guided our correlation of marine isotope stages and Heinrich layers as illustrated in Figure 6.

Downcore measurements of bulk density and P-wave velocity from core MD99-2237 were used to construct a synthetic seismogram (Fig. 6), which shows good correlation with the adjacent sparker section once the core is corrected for stretching. This correlation of the seismic record with the cores allows the purple reflection to be correlated somewhere within marine isotope stage 5a. We have considered and rejected an alternative correlation of purple with 20 m depth and pink with 35 m depth because preliminary indications are that marine isotope stage 5e was not recovered in this core. The preferred correlation in Figure 6 shows that acoustic facies A, with parallel, high-amplitude reflections, correlates with the glacial interval in the cores (marine isotope stages 2 to 5a), and acoustic facies B, with parallel, low-amplitude reflections, correlates with interglacial conditions, both in the upper 1 to 2 m of the cores (marine isotope stage 1) and in marine isotope stages 5b to 5e, below the purple reflection. The mean sedimentation rate for marine isotope stage 1 is 0.18 m/ka; the mean rate for marine isotope stages 2 to 4 is 0.10 m/ka. If the purple reflection is near the base of marine isotope stage 5a, then applying a marine isotope stage 1 sedimentation rate to the interval below purple implies that the pink reflector would have an age of about 140 ka. This age estimate suggests that pink represents the top of marine isotope stage 6, with an acoustic facies A similar to that in marine isotope stages 2 to 5a. A similar extrapolation of sedimentation rates suggests that the orange reflection represents the top of marine isotope stage 8.

INTERPRETATION OF THE GEOLOGICAL RECORD OVER THE PAST 250 KA

The distinctive alternation of acoustic facies A and B has been shown by correlation with cores to reflect an alternation between glacial and interglacial sedimentation conditions. Sedimentation rates are about twice as high during interglacial periods as during glacial periods. Using sedimentation rates and acoustic facies, a chronology back to marine isotope stage 8 can be reasonably extrapolated.

Mass-transport deposits are recognized in discrete zones separated by stratified sediment lacking mass-transport deposits. These zones appear to be downslope from scalloped indentations on the fault-line scarp (Fig. 2), suggesting that mass-transport deposits may have originated on the scarp and been focused by topography. Mass-transport deposits occur at three stratigraphic levels, two of which can be correlated with confidence between different geographic zones.

We consider that rare earthquakes are the most likely trigger for simultaneous failure and subsequent deposition of mass-transport deposits in geographically distinct zones separated by positive topographic features. We consider that dissociation of gas hydrate as a result of the reduction in pressure during falling sea level (Kayen and Lee, 1989) is unlikely to be a trigger, because failures did not occur at times of most rapid sea-level fall (e.g. during marine isotope stages 5a to 4 and 3 to 2). Mass-transport deposits, probably triggered by earthquakes, appear to have a recurrence interval of about 70 000 years.

REFERENCES

Hillaire-Marcel, C. and Turon, J.L.
1999: IMAGES V mission on the Marion Dufresne, 2nd leg, 30 June–24 July 1999; Geological Survey of Canada, Open File 3782.

Hillaire-Marcel, C., de Vernal, A., Bilodeau, G., and Wu, G.
1994: Isotope stratigraphy, sedimentation rates, deep circulation, and carbonate events in the Labrador Sea during the last ~200 ka; Canadian Journal of Earth Sciences, v. 31, p. 63–89.

Hiscott, R.N., Aksu, A.E., Mudie, P.J., and Parsons, D.F.
2000: A 340 000 year record of ice rafting, palaeoclimate fluctuations, and shelf-crossing glacial advances in the southwestern Labrador Sea; Global and Planetary Change, v. 28, p. 227–240.

Kayen, R.E. and Lee, H.J.
1989: Effect of sea-level-fall-induced gas-hydrate decomposition on stability of continental slope, Beaufort Sea; EOS, v. 70, p. 1152.

Keen, C.E. and Beaumont, C.
1990: Geodynamics of rifted continental margins; Chapter 9 in Geology of the Continental Margin of Eastern Canada, (ed.) M.J. Keen and G.L. Williams; Geological Survey of Canada, Geology of Canada, no. 2, p. 391–472 (also Geological Society of America, The Geology of North America, v. I-1, p. 391–472).

Piper, D.J.W., Pirmez, C., Manley, P.L., Long, D., Flood, R.D., Normark, W.R., and Showers, W.
1997: Mass transport deposits of Amazon Fan: Scientific Results, Ocean Drilling Program, v. 155, p. 109–146.

Piper, D.J.W., Skene, K.I., and Morash, N.
1999: History of major debris flows on the Scotian Rise: Geological Survey of Canada, Current Research 1999-E, p. 203–212.

Posamentier, H.W.
2001: Geomorphic, stratigraphic, and seismic visualisation analysis of deepwater deposits; Bulletin, Houston Geological Society, v. 43, p. 1–25.

Shipboard Scientific Party.
1972: Site 111; in Initial Reports of the Deep Sea Drilling Project, Volume XII, (ed.) A.S. Laughton, W.A. Berggren, et al.; United States Government Printing Office, p. 33–159.

Geological Survey of Canada Project 980013